

# Transverse Spin Physics with PHENIX

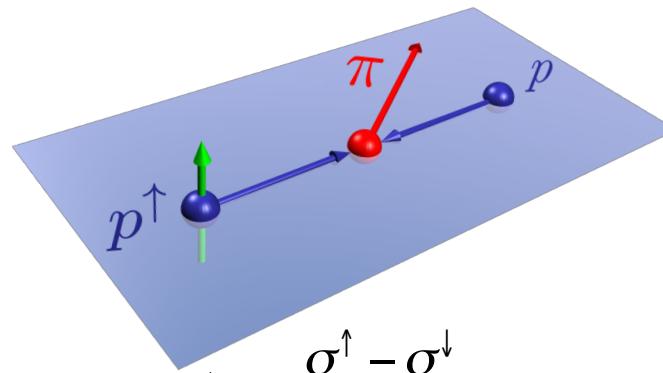
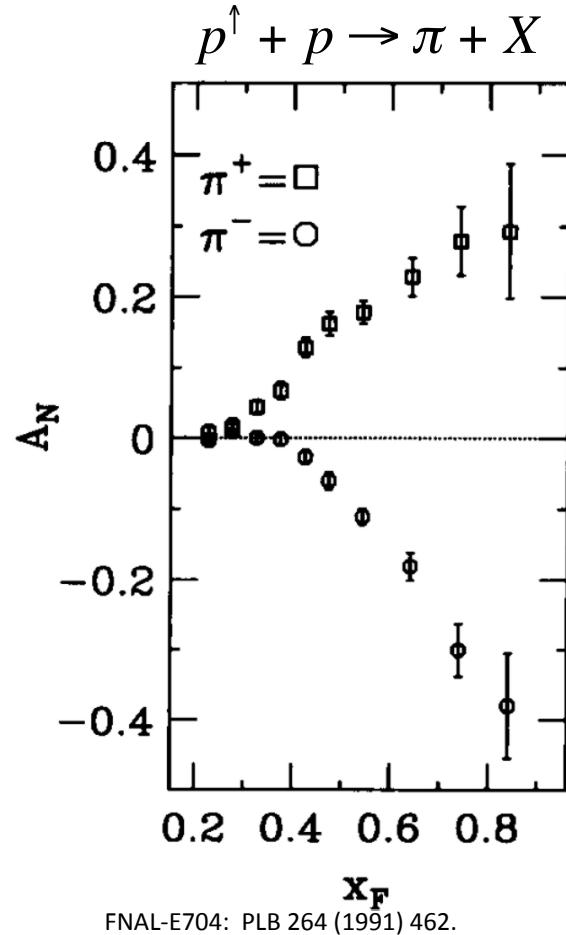
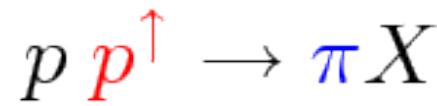
Xiaodong Jiang

Los Alamos National Laboratory

June, 12<sup>th</sup>, 2012@RHIC/AGS User's Meeting Spin Workshop

- Updates of Preliminary SSA Results.
- Run2012 transverse p+p data.
  - FVTX commissioning.
  - Single-muon triggers for  $p>5$  GeV (SG3 trigger).
- Expectations for Run2013 p+p@510 GeV.
  - Drell-Yan longitudinal spin observables at 510 GeV.
- Run2014 and beyond
  - MPC-EX upgrade. Prompt photon SSA.
- sPHENIX forward upgrade, for SSA (tomorrow's talk).

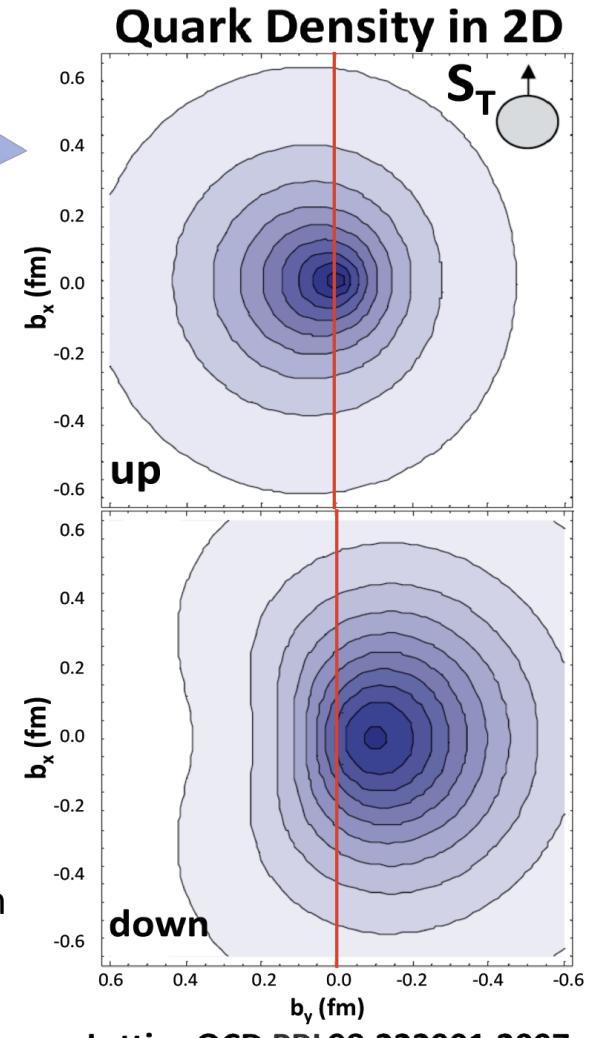
# Quarks can tell left-right in



$\pi^+$  ( $u\bar{d}$ ) favors left

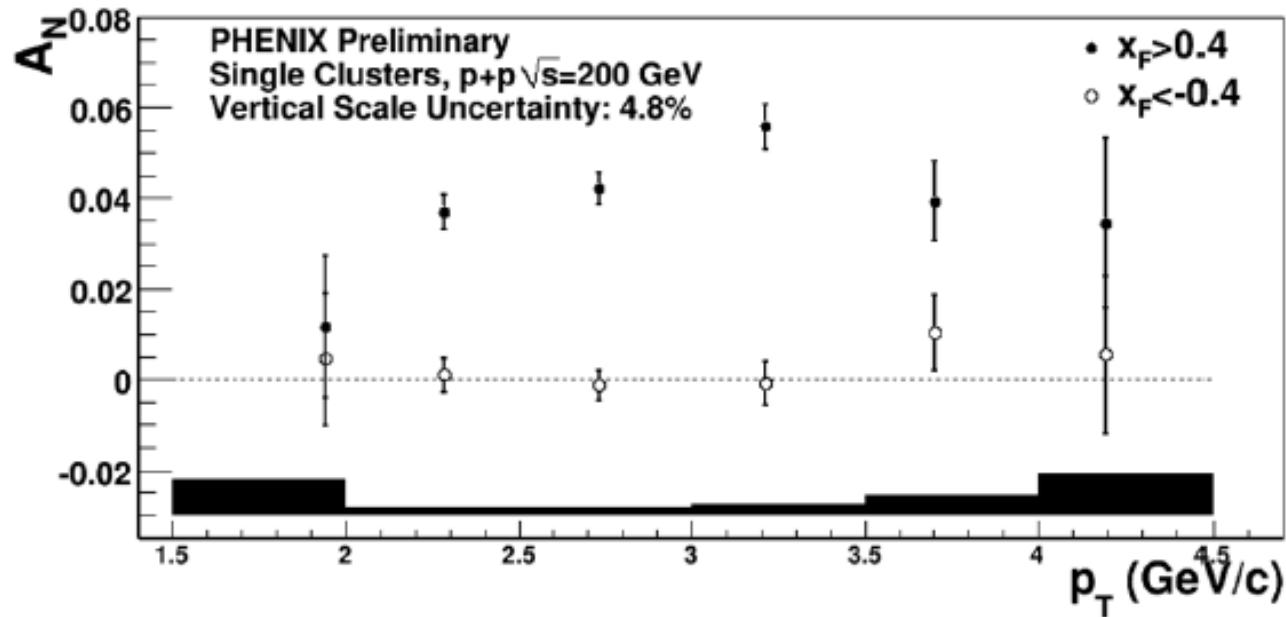
$\pi^-$  ( $d\bar{u}$ ) favors right

One possible explanation (Sivers effect): quark's transverse motion generates a left-right bias.



up-quarks favor left ( $L_u > 0$ ), down-quarks favor right ( $L_d < 0$ ).

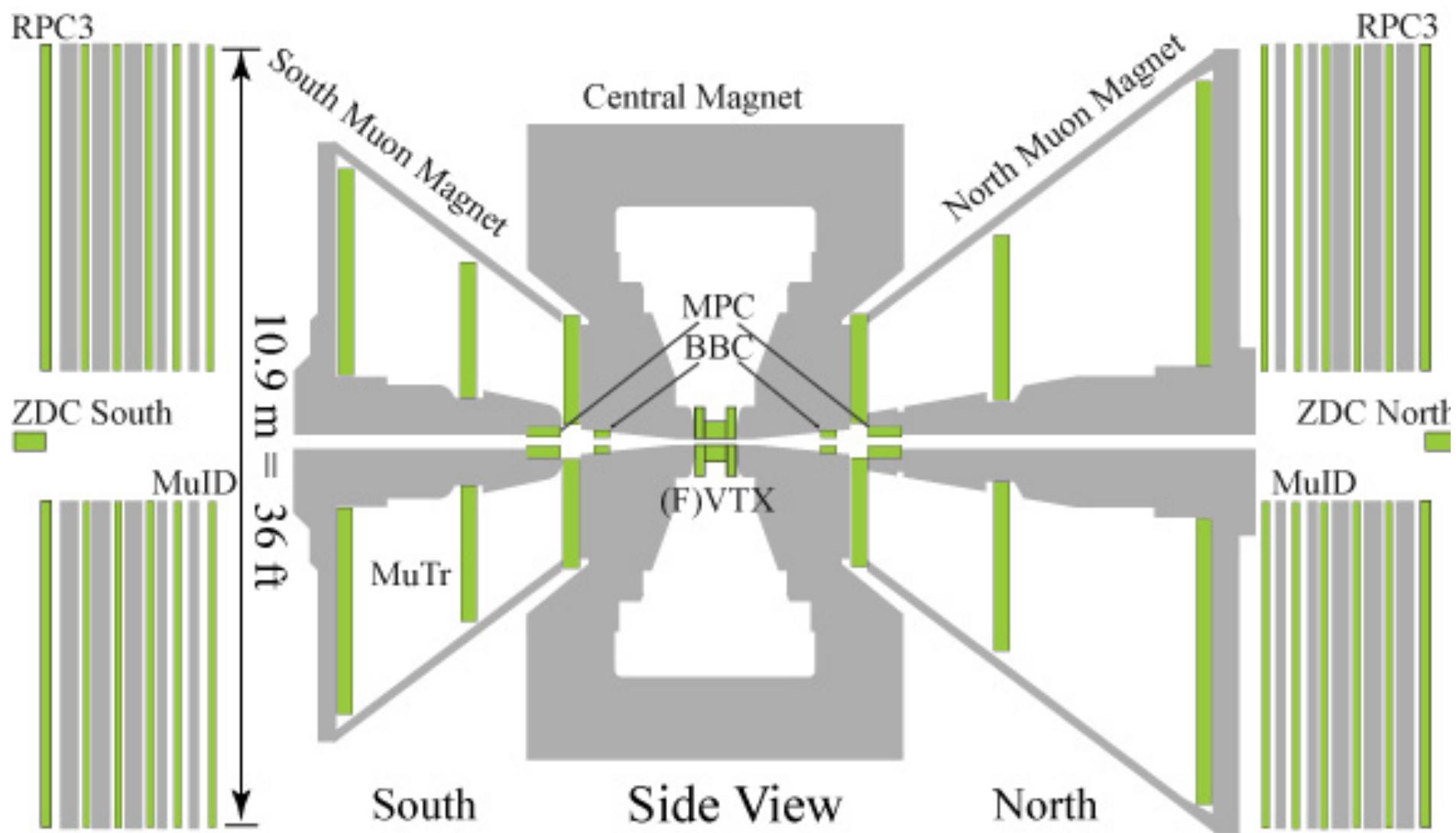
# SSA observed in PHENIX: MPC Single Clusters



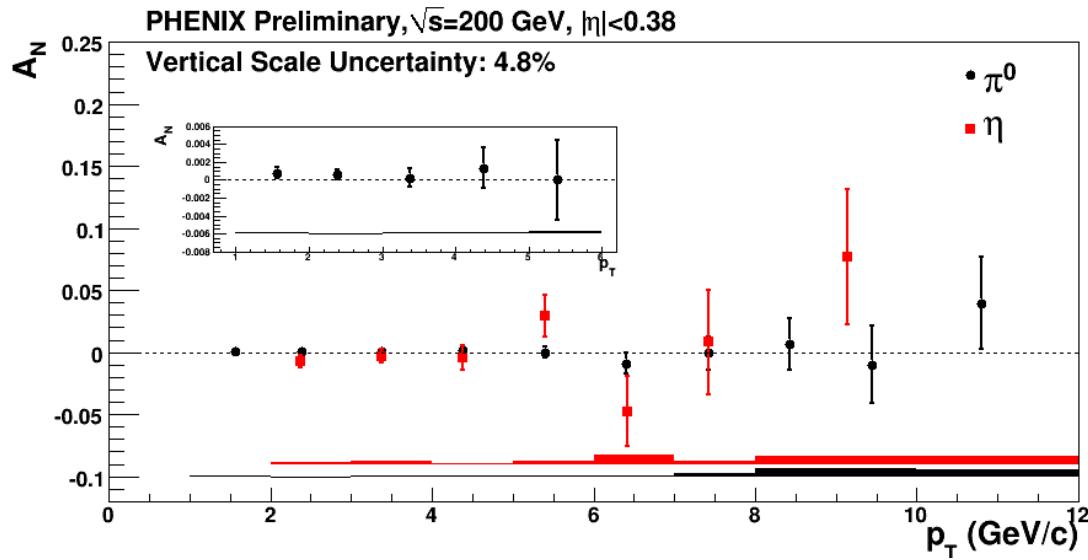
However, two mechanisms can not be distinguished in  $A_N$  of inclusive hadron production in  $p+p$ :

Collins effect: quark transverse spin (transversity) generates a left-right bias through fragmentation.

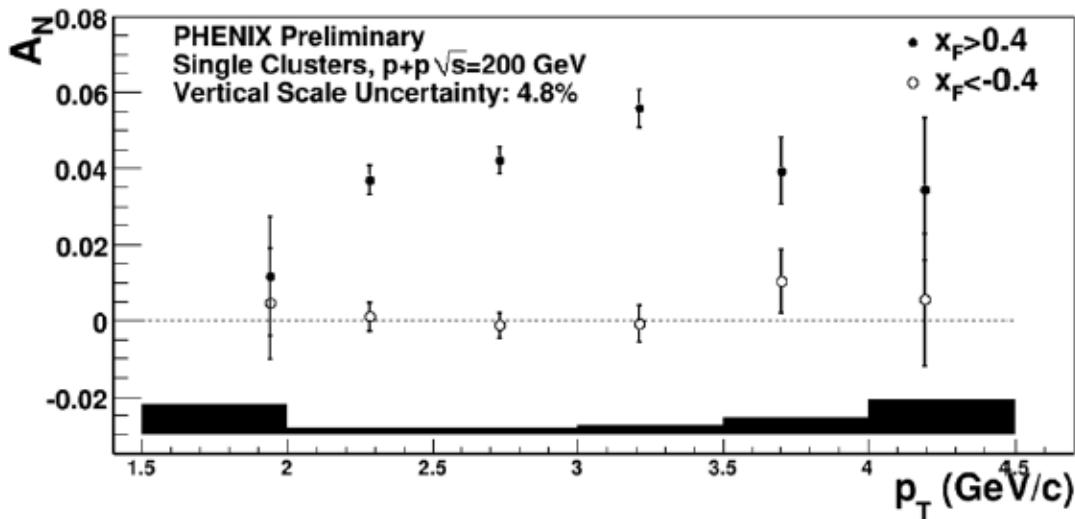
Sivers effect: quark transverse motion generates a left-right bias.



# Inclusive Meson SSA



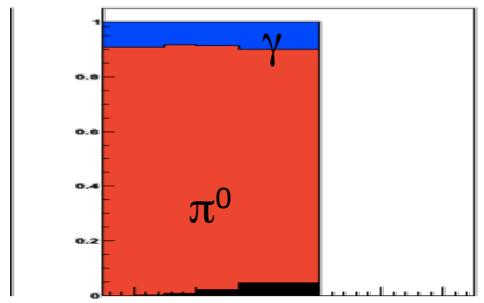
PHENIX Central arm:  
mid-rapidity  
(preliminary from April 2010).  
20x FOM compared to PRL 95,  
202001 (2005)



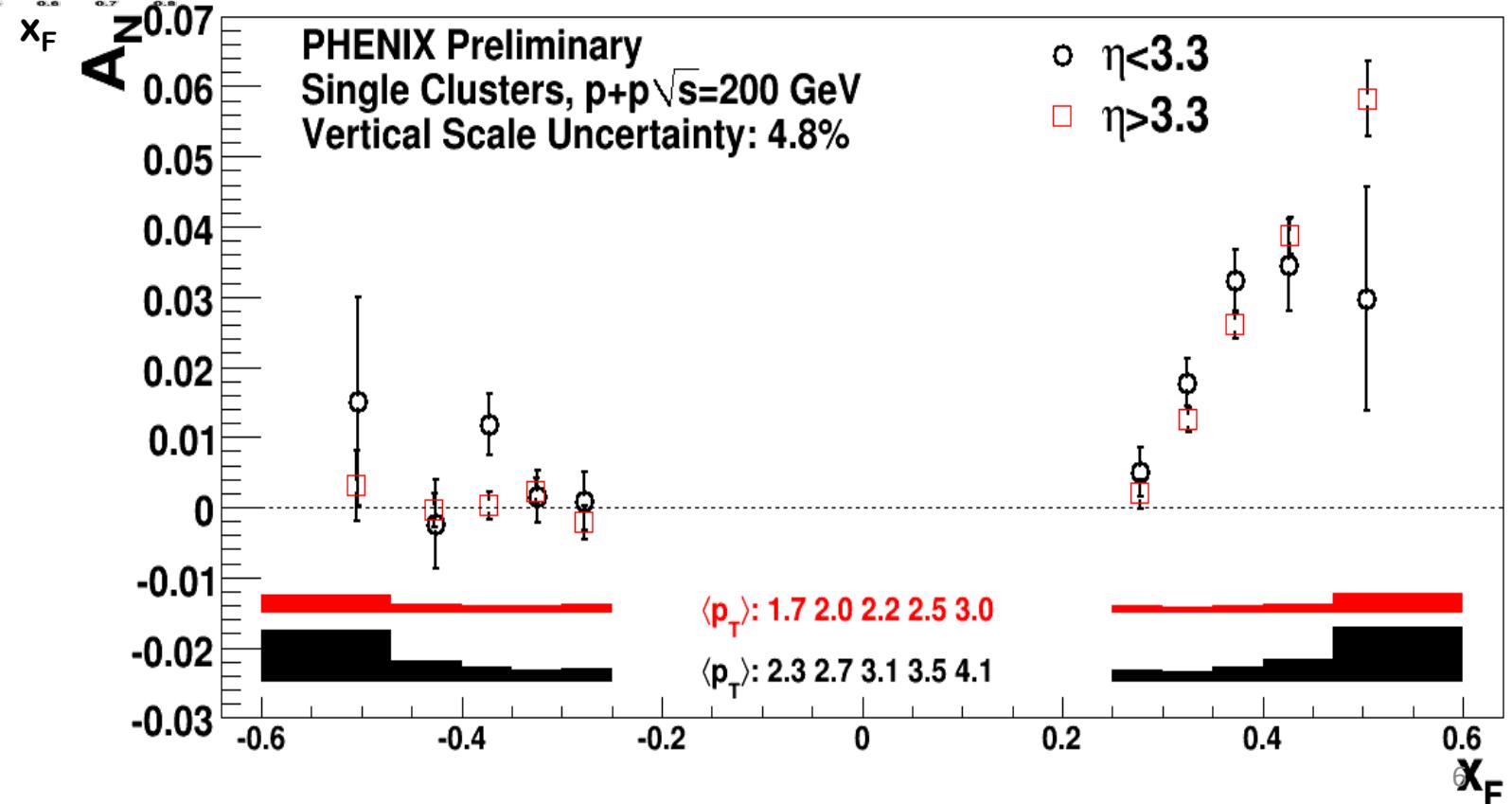
PHENIX MPC forward  
rapidity inclusive cluster  
(dominated by  $\pi^0$ )

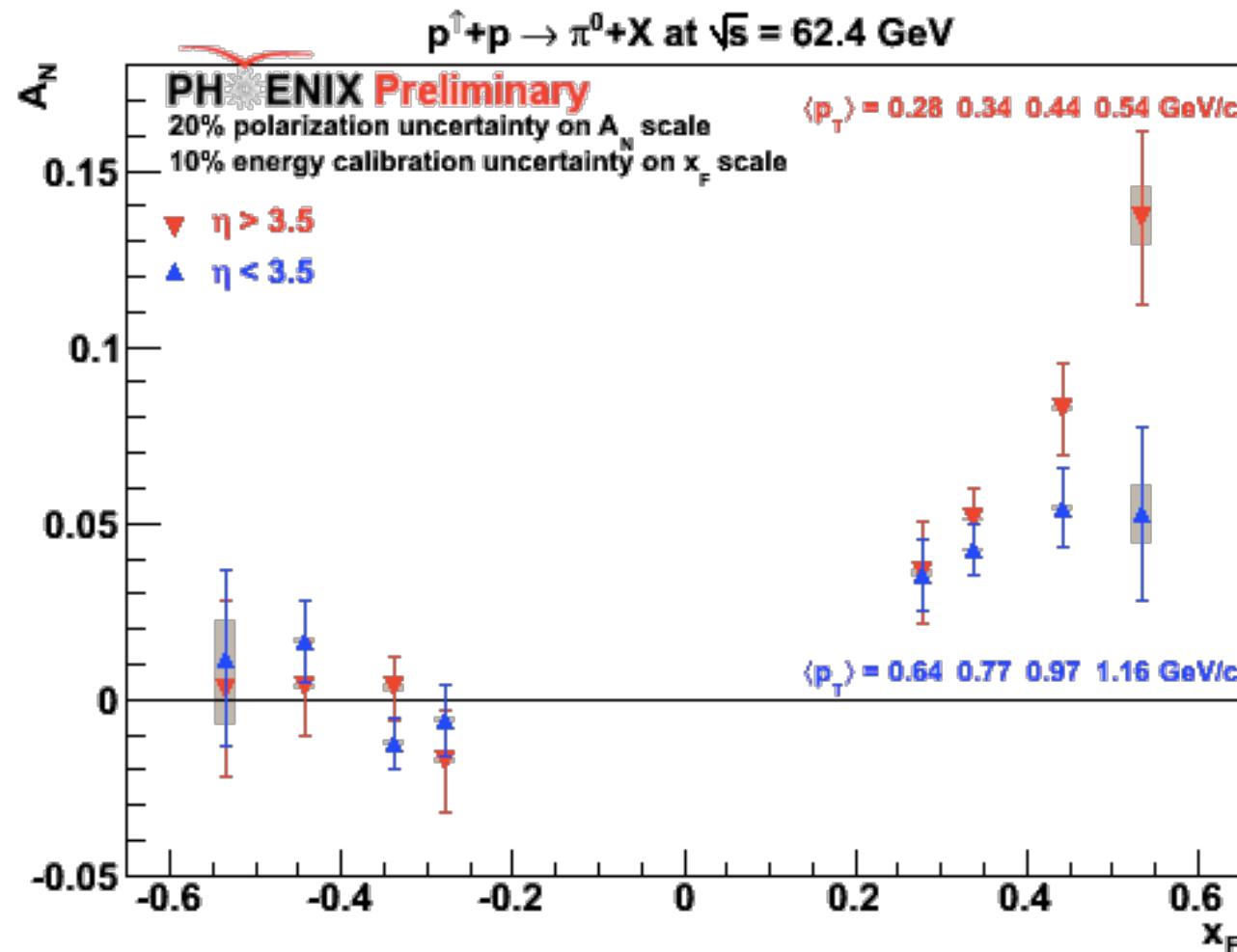
# Single Cluster $A_N$ vs $x_F$

Cluster Contributions



PHENIX MPC @200 GeV



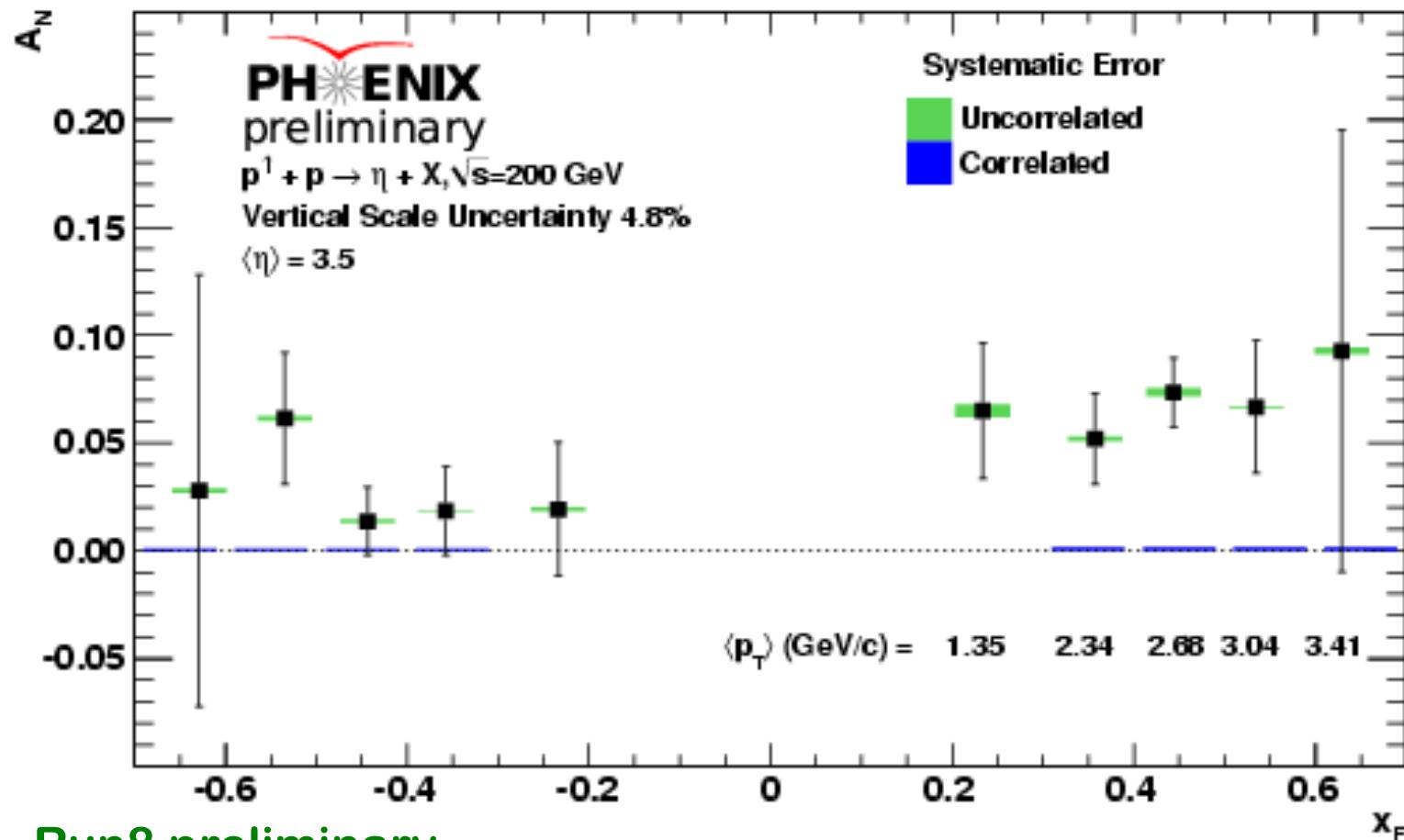


At 62.4 GeV.

Asymmetries: forward region  $\pi^0 \ 3.1 < |\eta| < 3.9$ , 62.4 GeV

- No strong dependence on  $\sqrt{s}$

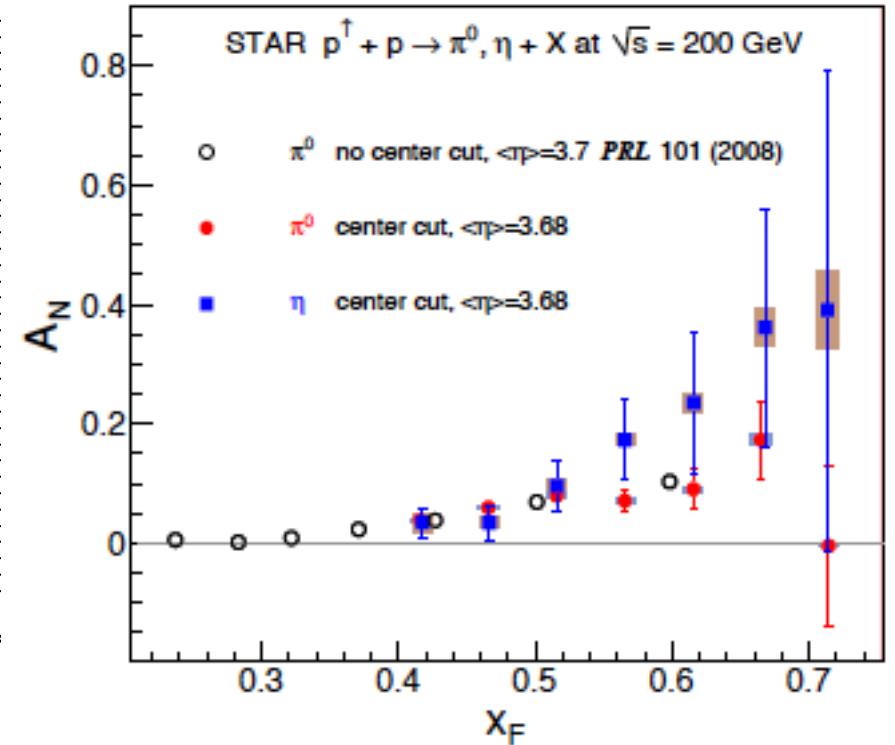
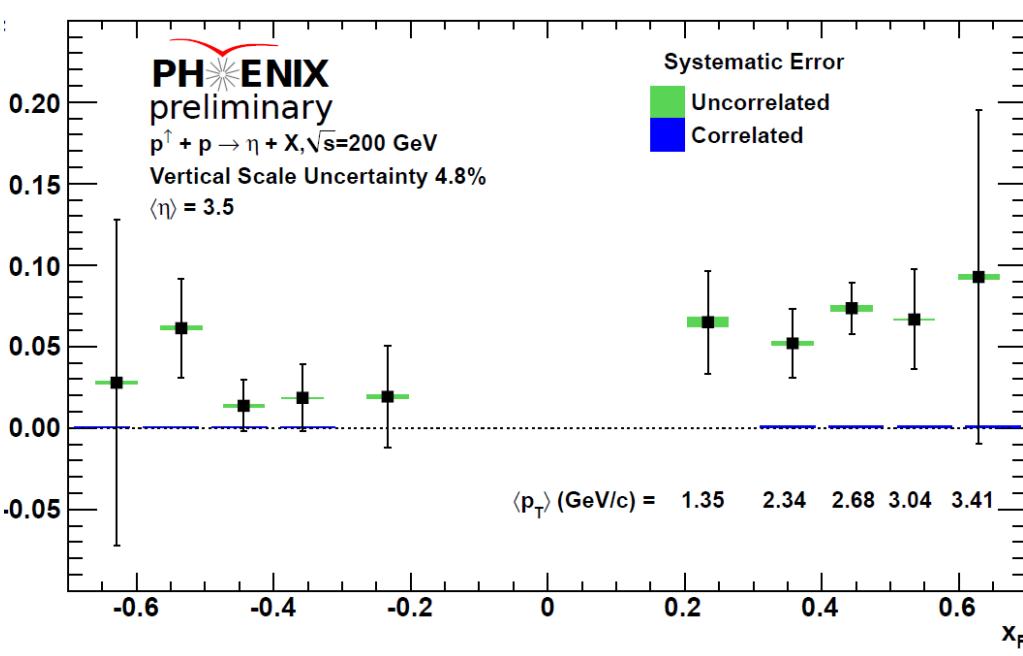
# $\eta$ Transverse Asymmetries



Run8 preliminary

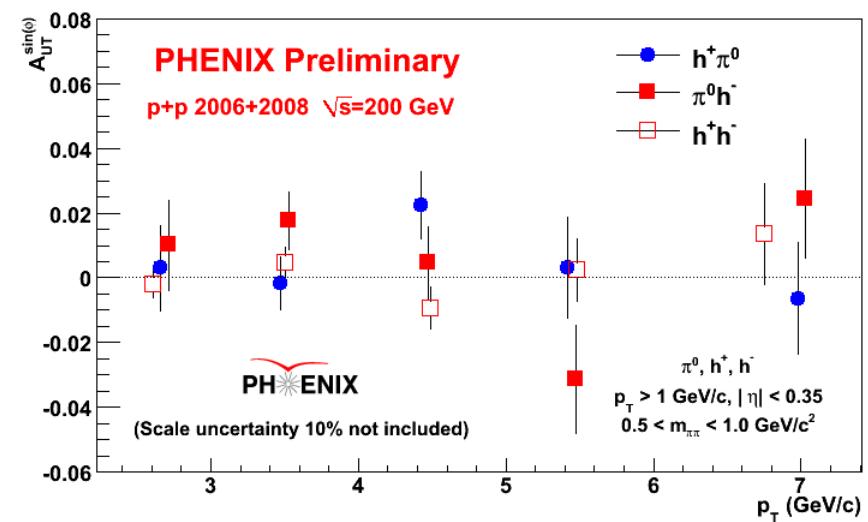
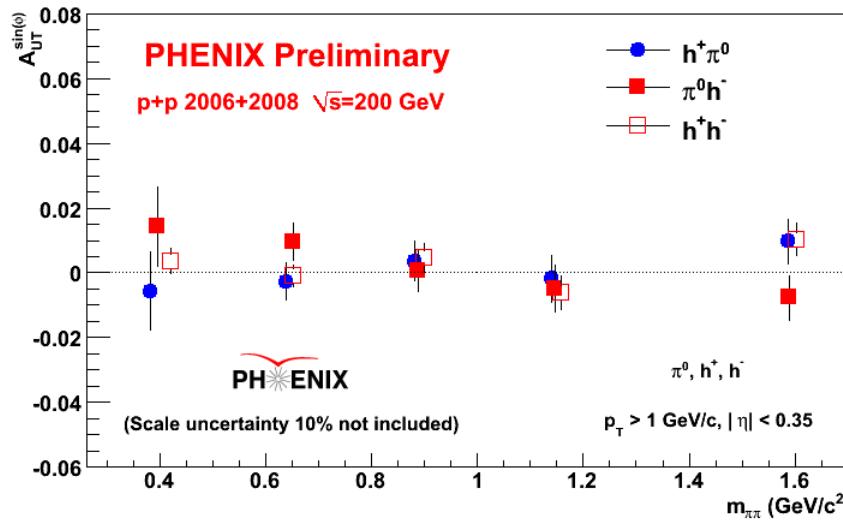
Working on cross sections

# Asymmetries Forward Region: $\eta$ @ 200 GeV



Significant asymmetries observed.

# SSA: Hadron Correlation Measurements to Access Quark Transversity



Phenix at Midrapidity: Small SSA in correlated hadron pairs

# PHENIX Preliminary SSA from Other Probes

Preliminary results from earlier analysis

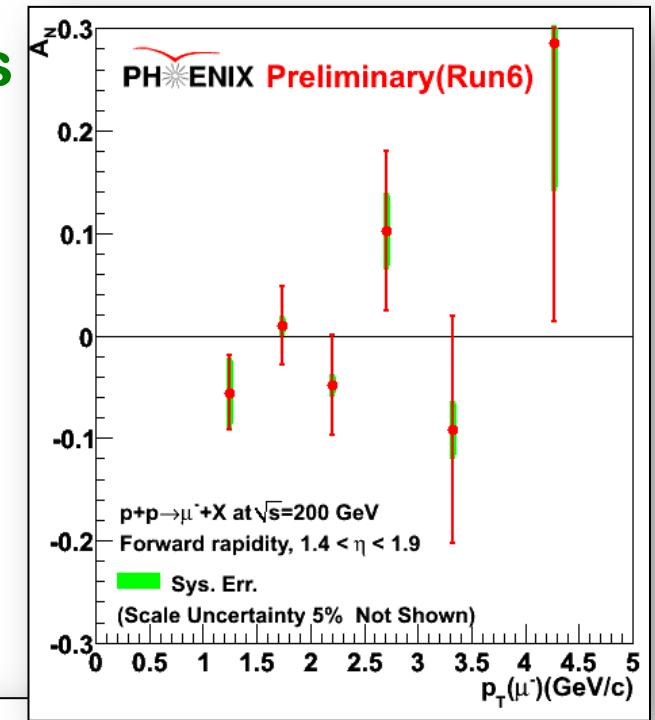
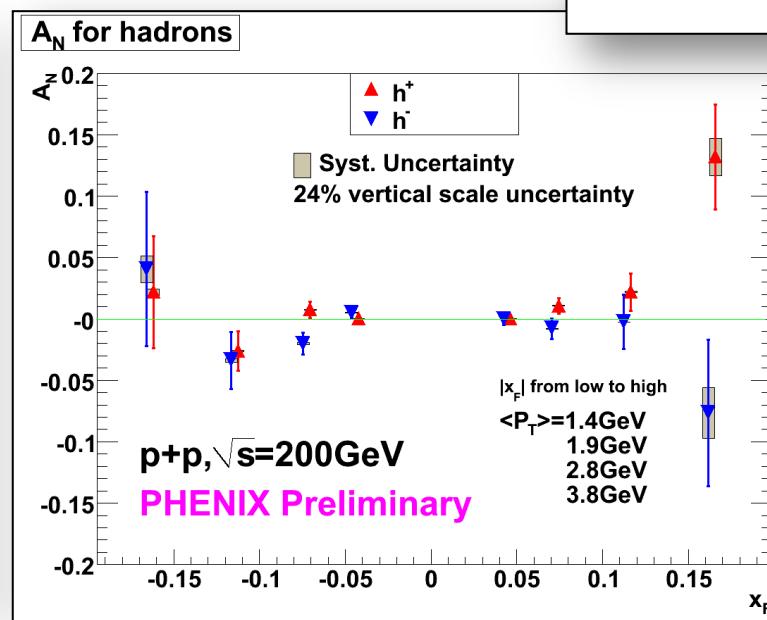
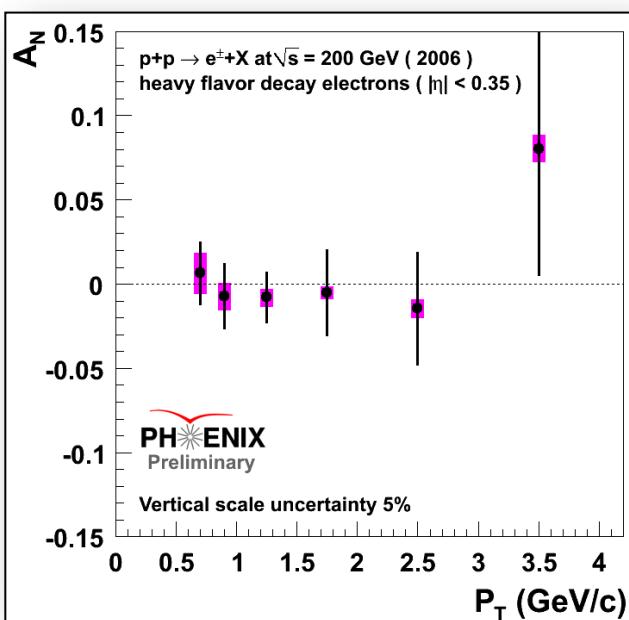
Heavy flavor decayed single-muons

Punch-through hadrons

Electrons at central rapidity.

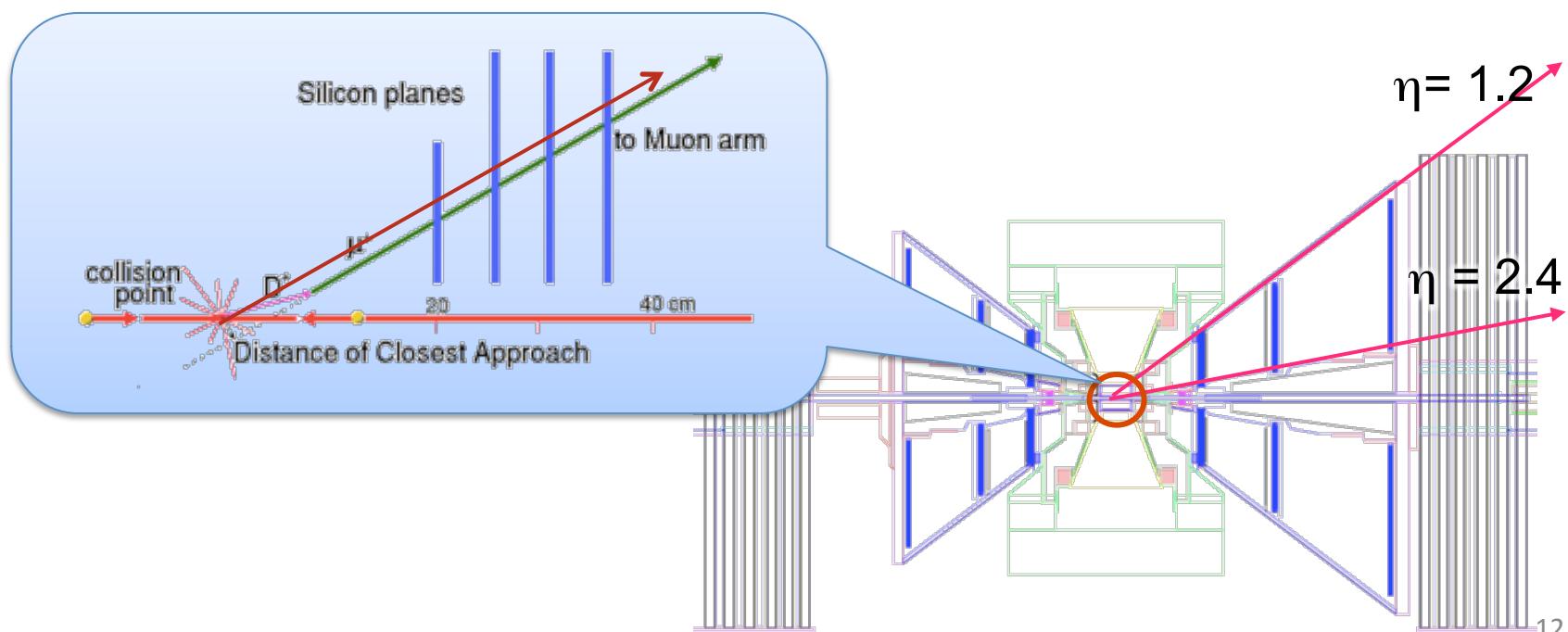
Di-hadron back-to-back correlations

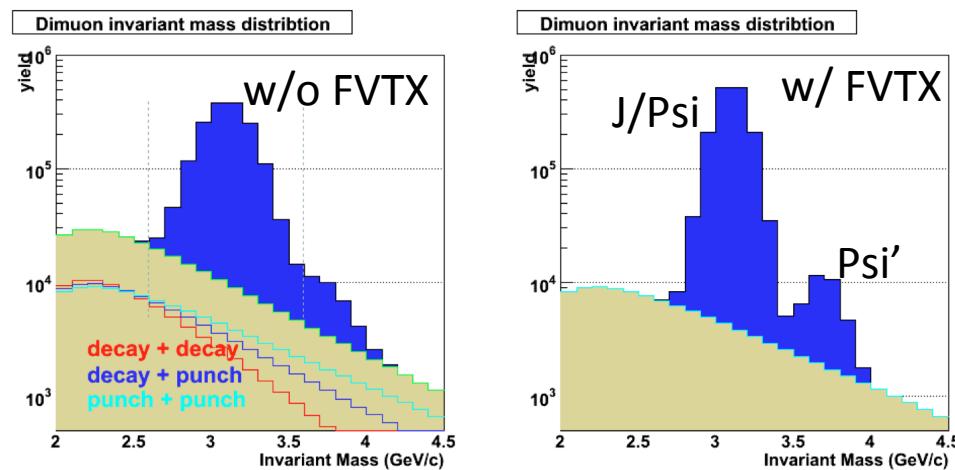
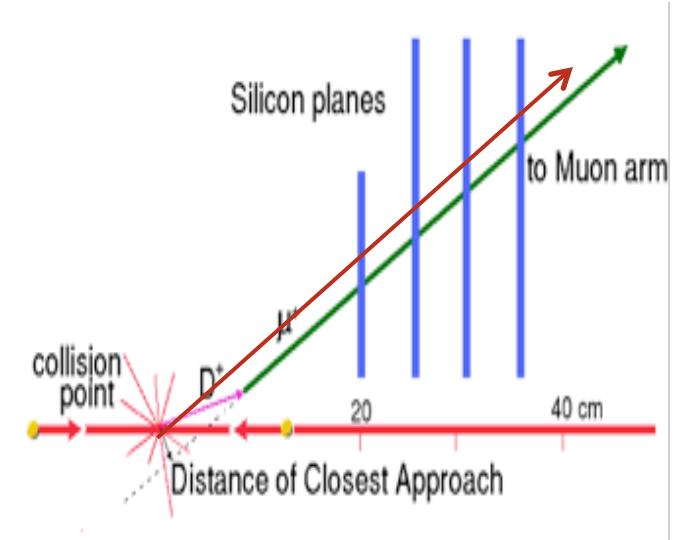
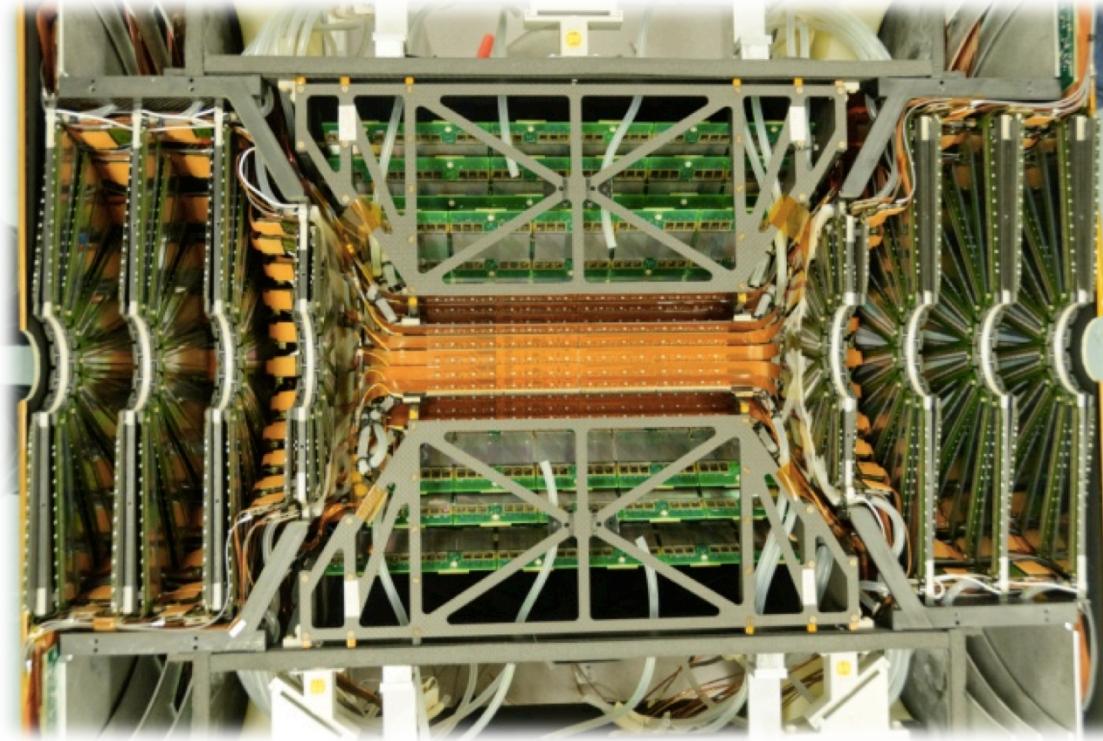
No significant SSA observed.



# New Developments in Run12: Forward Vertex Detectors (FVTX)

- Tracking in forward region and close to IP
- Provide
  - Differentiate primary vertex / secondary decay
  - Track isolation : suppress hadrons.
  - Precisely measure opening angle : J/ $\psi$  mass
  - Jointed tracking with MuTr : suppress delay-in-flight





Dimuon Mass (pp@200GeV simulation)

### New Tools:

- Open D, B decay muons.
- J/psi, Psi'
- Drell-Yan
- W<sup>+-</sup>

# New Developments During Run12

SG3 trigger, for heavy flavor decayed muons.

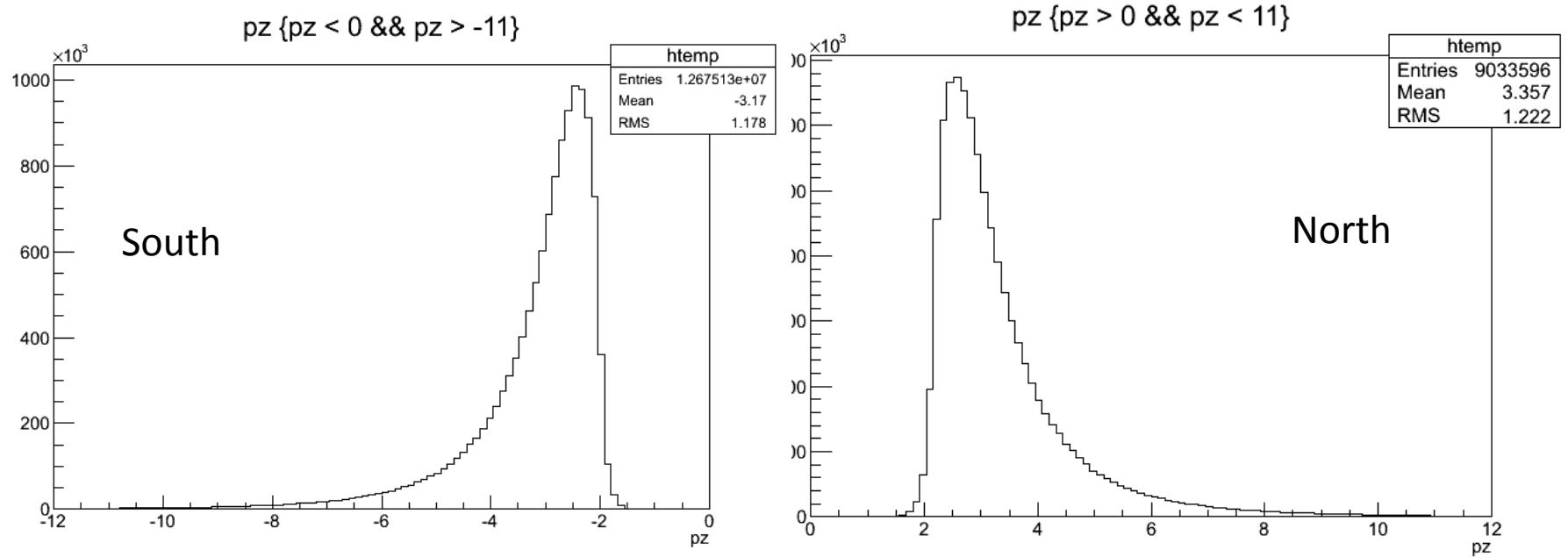
**Goal: to obtain high statistic data on muTr singles.**

Event data needed: single-muons for physics  $A_N$  prefer  $p> 5 \text{ GeV}/c$ , as much as possible.

Preparations:

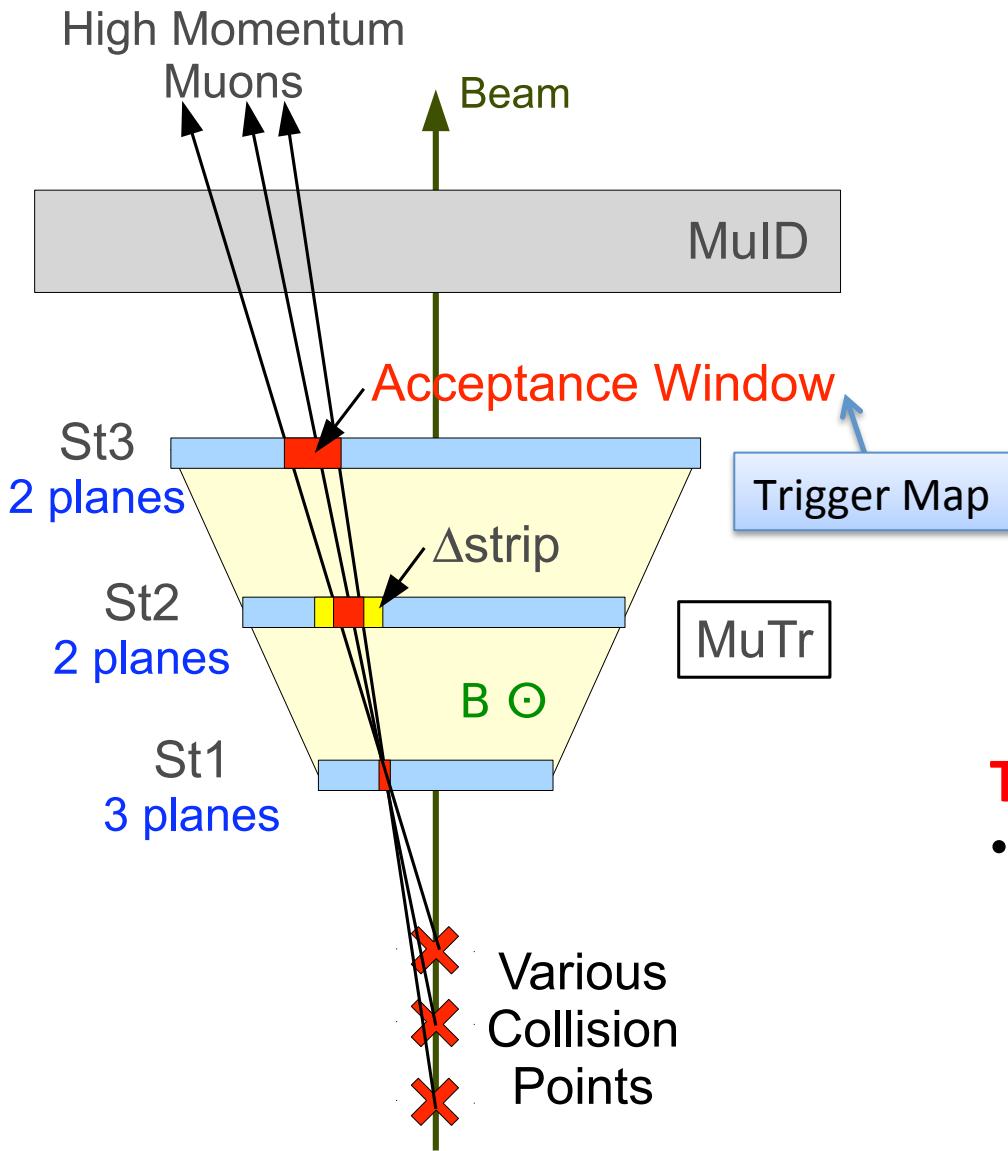
- hit patterns of **muTrg SG3** for  $p>4 \text{ GeV}/c$  muons.
- verify trigger efficiency by emulation code and by data.
- adjust prescale factors online for best statistics.
- Verify again by data, compare SG3 vs MB trigger.

## BEFORE: Run6 Single-Muon A<sub>N</sub> accepted muon events. Momentum Distribution.



peaked at 2.5 GeV/c

Run6 data single muons: mostly at low momentum ( $\pi/K$  decay dominate).  
Would prefer the trigger setup to pick-up more higher momentum muons ( $p>5$  GeV/c).

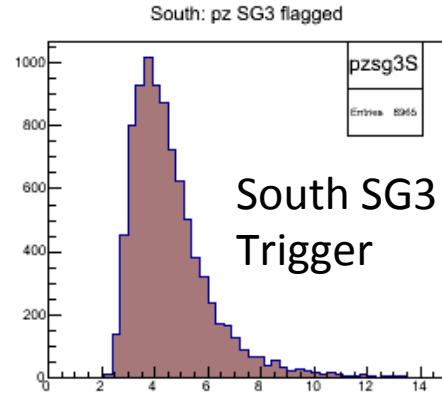
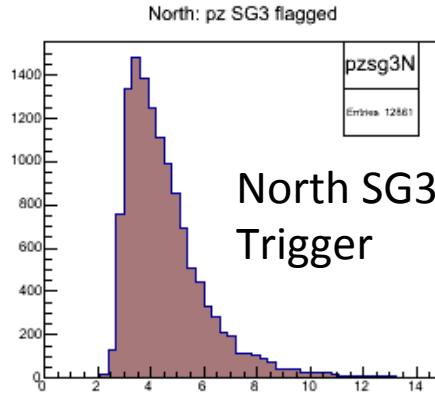


- Developed SG3 trigger map.
- Optimize operating condition
  - Tolerance in hit pattern map.
  - Rates vs prescale factors.
  - Turn-on curve analysis to verify trigger efficiency.

### Trigger added

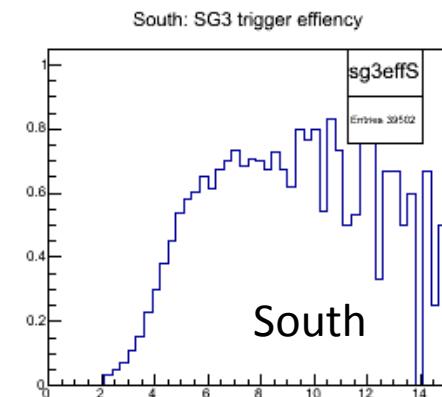
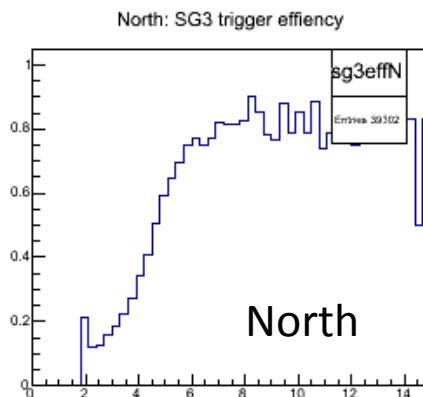
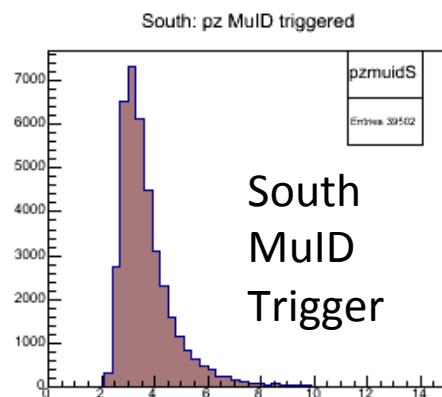
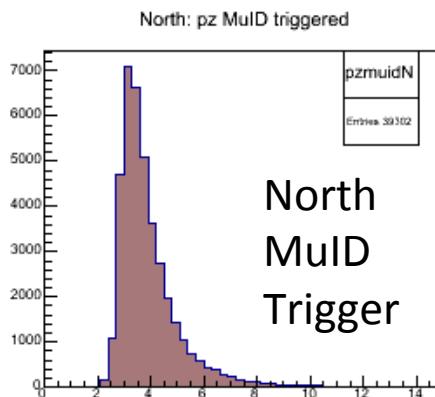
- Muon: SG3&MuID1D  
(prescaled to ~150Hz)

Figure 29: Explanatory drawing for the trigger logic.



AFTER

**peaked at 4 GeV/c**

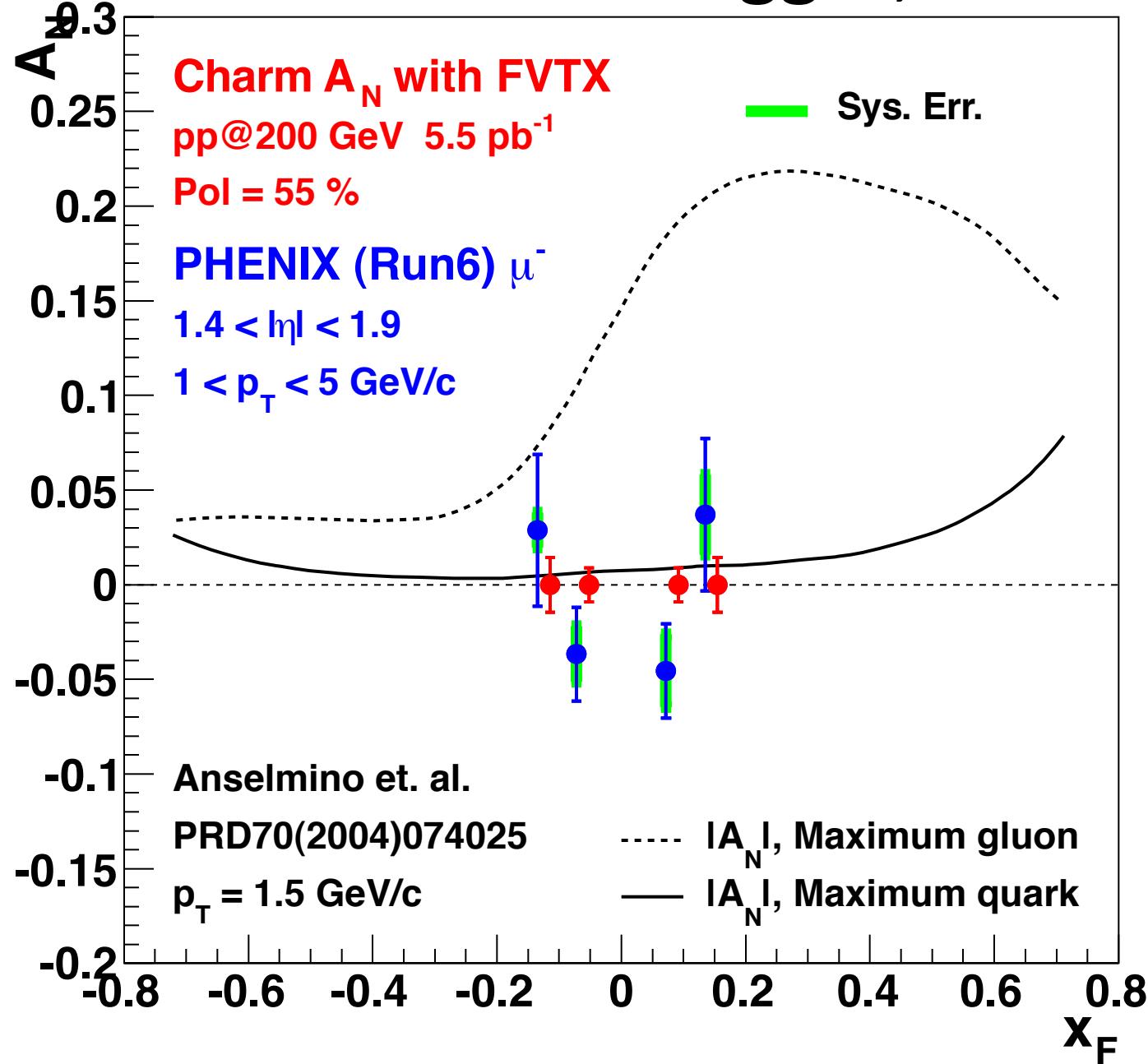


SG3 single-muon trigger efficiencies

“Heavy Flavor muon trigger” functioned at the end of 200 GeV p+p run, and in 510 GeV p+p run during run12.

Muon momentum (GeV/c)

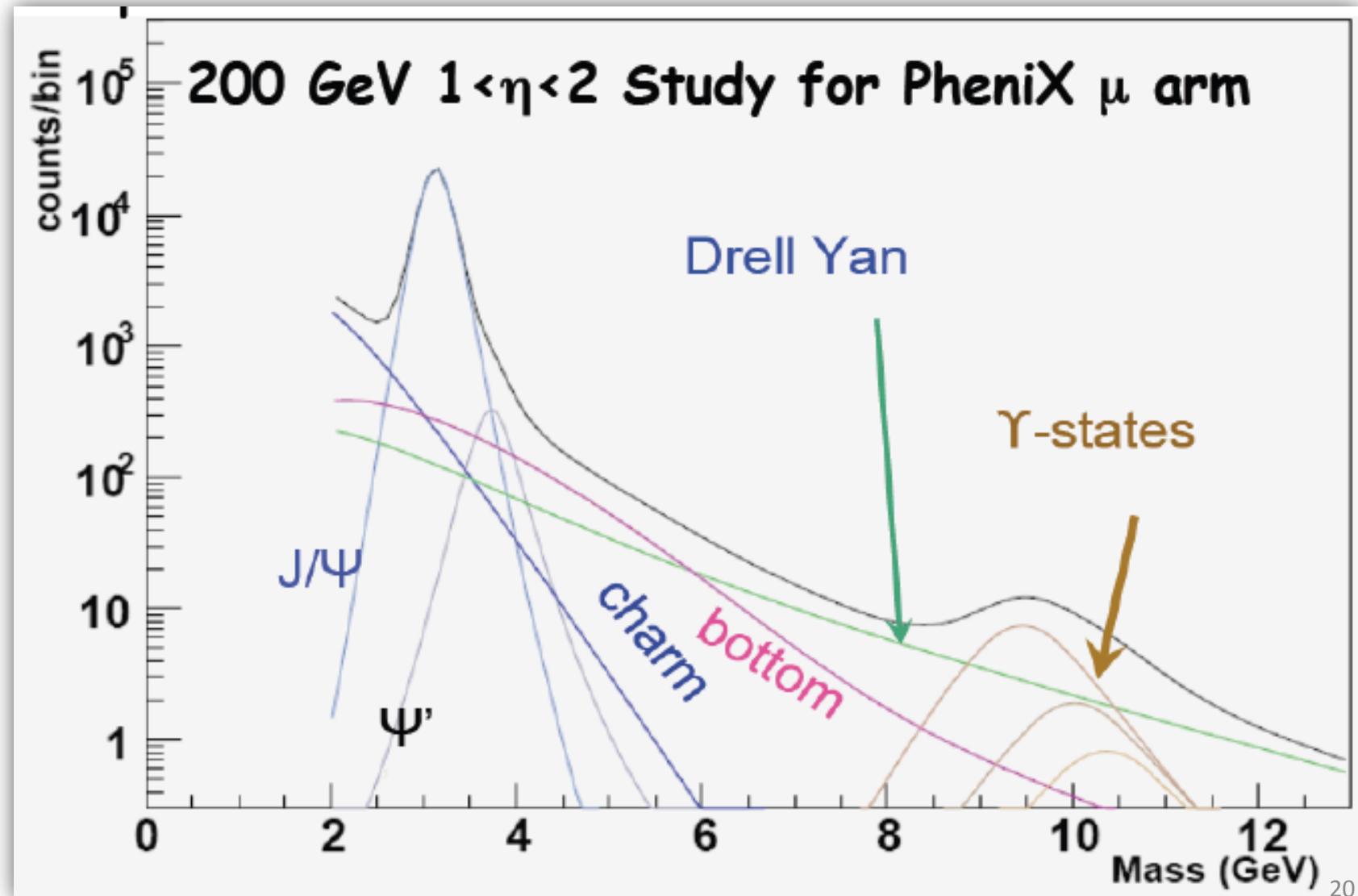
with FVTX and SG3 trigger, for run 14



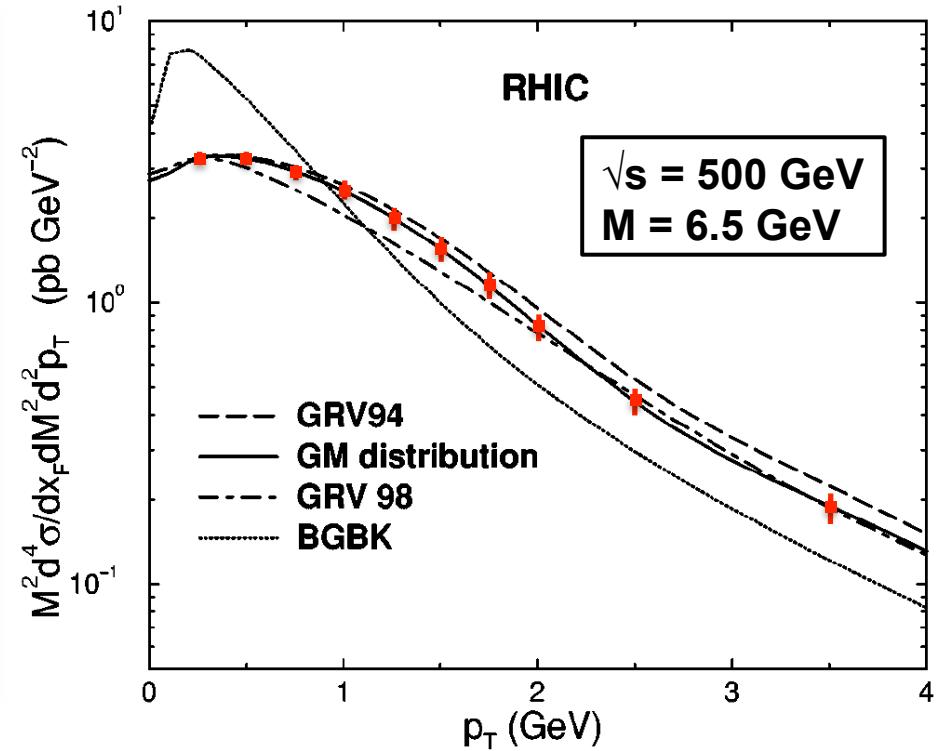
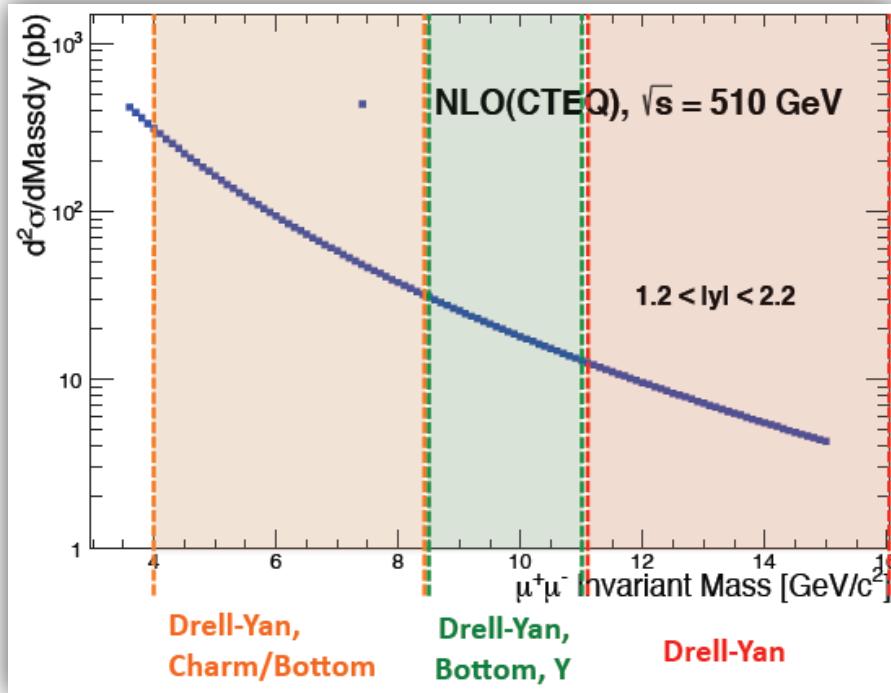
## FVTX+MuTr Spin Observables (selected)

|                      |                    | Parity-Violating           | Parity-Conserving       |                            | comments |
|----------------------|--------------------|----------------------------|-------------------------|----------------------------|----------|
|                      |                    |                            | $A_L$                   | $A_N$                      |          |
| single- $\mu$        | $W^\pm$ decay      | $\Delta q, \Delta \bar{q}$ | -                       | -                          | L++      |
|                      | heavy flavor decay | x                          | g-Sivers                | $\Delta g$                 |          |
| di- $\mu$            | J/ $\Psi$          | x                          | g-Sivers                | $\Delta g$                 |          |
|                      | Drell-Yan          | x                          | q-Sivers<br>qbar-Sivers | $\Delta q, \Delta \bar{q}$ | L++      |
|                      | $Z^0$              | $\Delta q, \Delta \bar{q}$ | -                       | -                          | (L++++)  |
| cluster-hits         |                    | x                          | q-Sivers                | $\Delta q, \Delta \bar{q}$ |          |
| correlated-particles |                    | x                          | q-transversity          |                            |          |

# FVTX can better isolate Drell-Yan pairs in di-muon events



# Drell-Yan with MuTr+FVTX



PHENIX projection:  $\sqrt{s} = 510 \text{ GeV}$

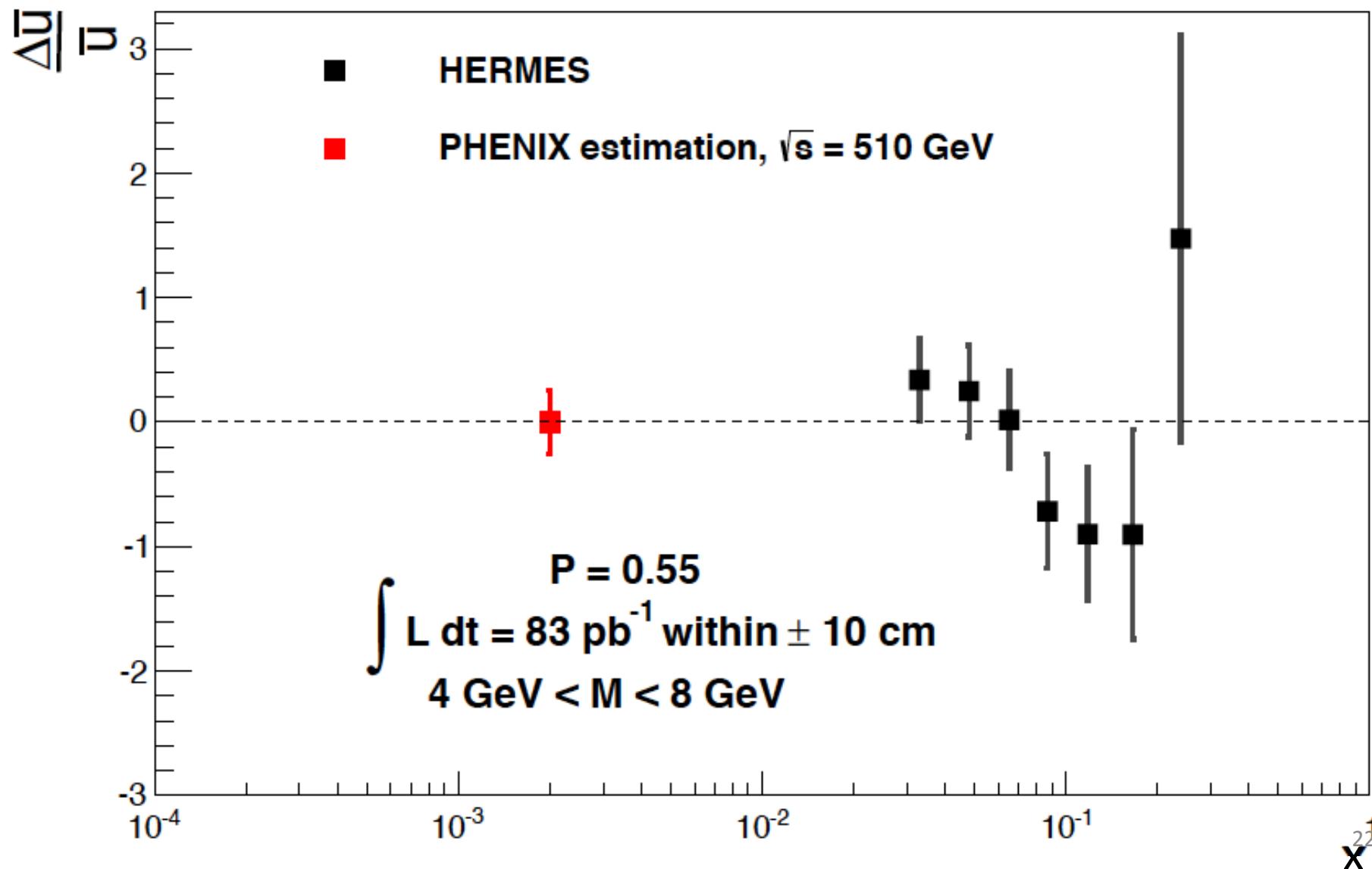
Integrated luminosity  $83 \text{ pb}^{-1}$

PHENIX muon arms:  $1.2 < \eta < 2.2$

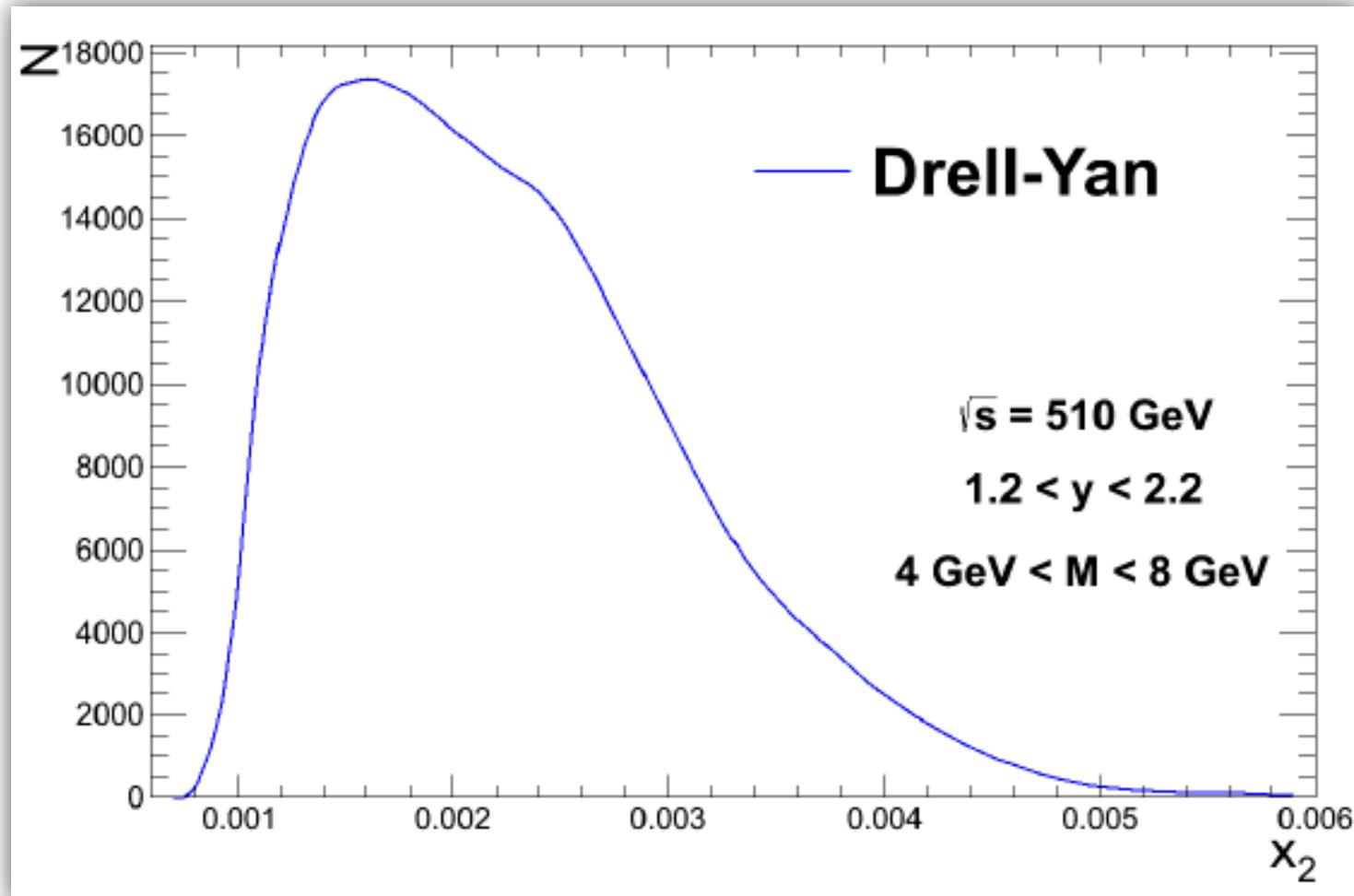
Run13 Expectations:  
Drell-Yan  $p_T$  dependence

# Run13 Expectation: Drell-Yan $A_{LL}$

Converted to LO sea-quark helicity



Access to sea quark  $\langle x \rangle \sim 0.002$

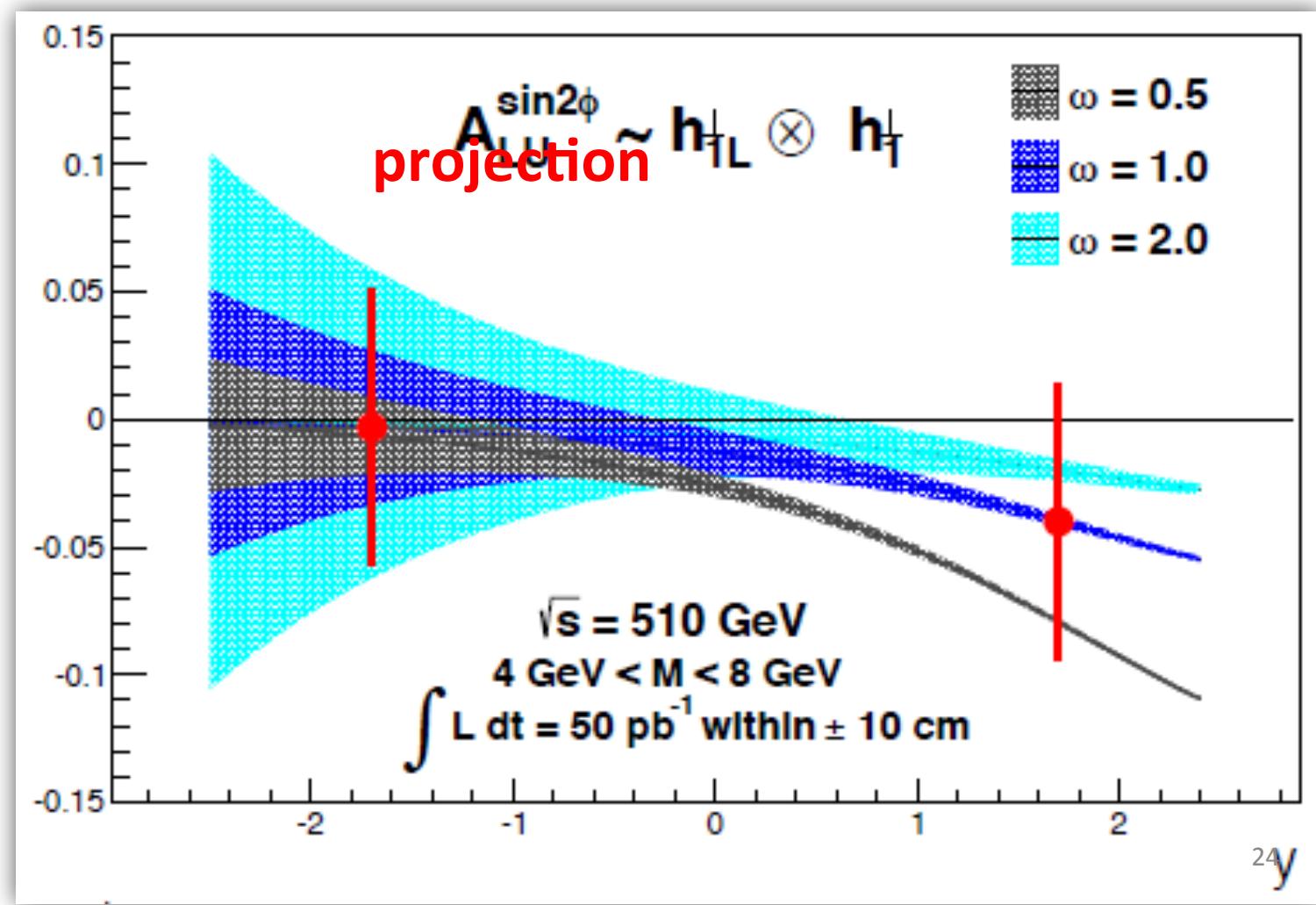


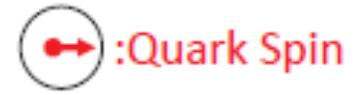
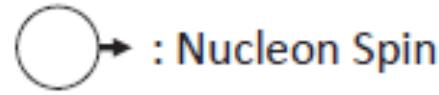
# Run13 Expectation: Drell-Yan $A_{LU}$

Access to quark “longitudinal-transversity” (one of 8-TMDs)

Transverse quark polarization in a longitudinally polarized nucleon.

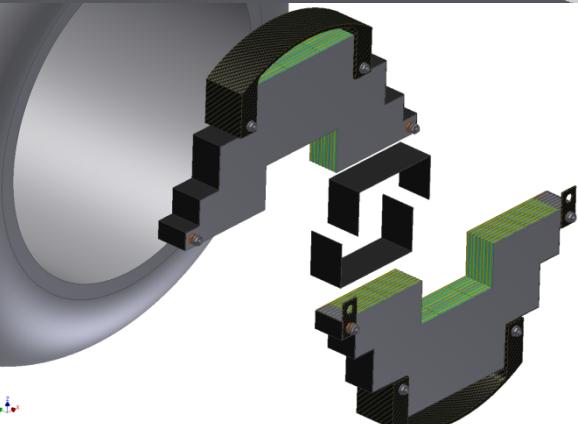
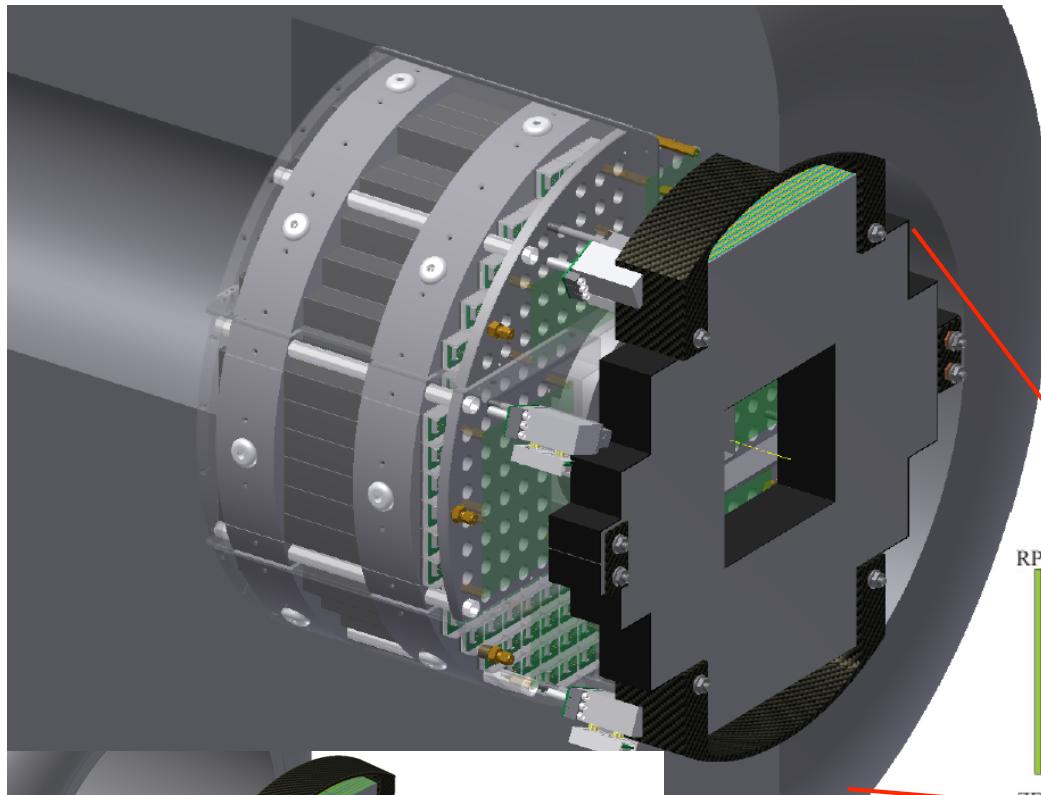
arXiv:1108.4974 (Lu, Ma, Zhu)





|                      |   | Quark polarization                           |  |   |
|----------------------|---|--|--|---|
|                      |   | Unpolarized (U)                              | Longitudinally Polarized (L)                                     | Transversely Polarized (T)  |
| Nucleon Polarization | U | $f_1 = \bullet$                              |  | $h_1^\perp = \bullet - \bullet$<br>Boer-Mulders   |
|                      | L |  | $g_{1L} = \bullet \rightarrow - \bullet \rightarrow$<br>Helicity | $h_{1L}^\perp = \bullet \rightarrow - \bullet \rightarrow$<br>Worm Gear                         |
|                      | T | $f_{1T}^\perp = \bullet - \bullet$<br>Sivers | $g_{1T} = \bullet - \bullet$<br>Worm Gear                        | $h_1 = \bullet - \bullet$<br>Transversity<br>$h_{1T}^\perp = \bullet - \bullet$<br>Pretzelosity |

# PHENIX Beyond Run14: The MPC-EX Detector

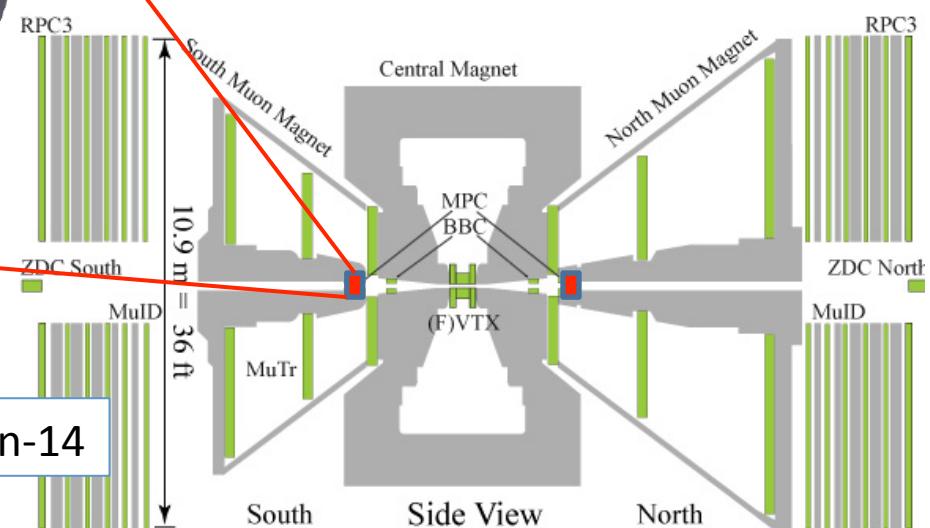


$3.1 < \eta < 3.8$

To be ready for Run-14

A combined charged particle tracker and EM preshower detector – dual gain readout allows sensitivity to MIPs and full energy EM showers.

- $\pi^0$  rejection (direct photons)
- $\pi^0$  reconstruction out to  $>80\text{GeV}$
- Charged track identification

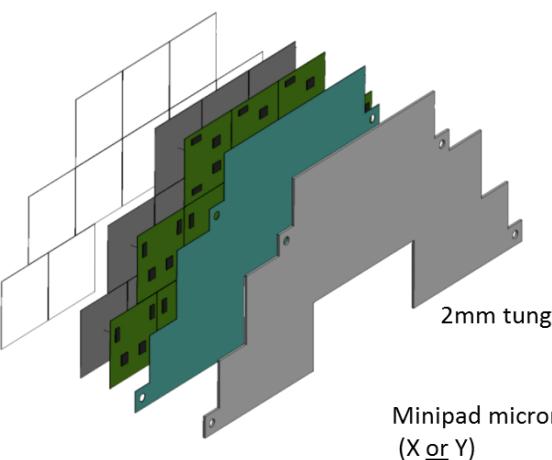
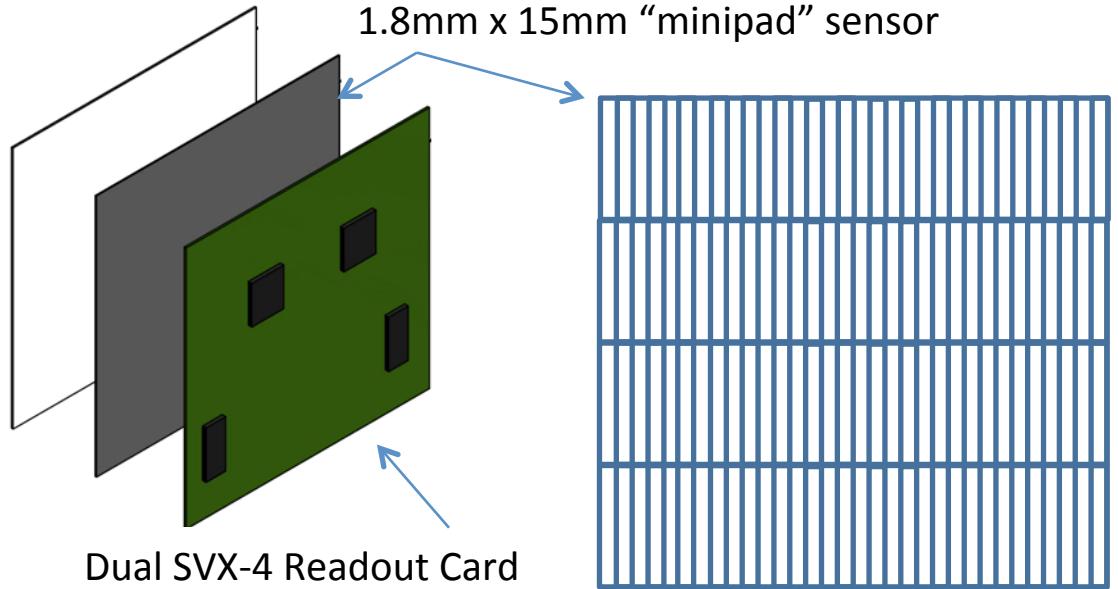
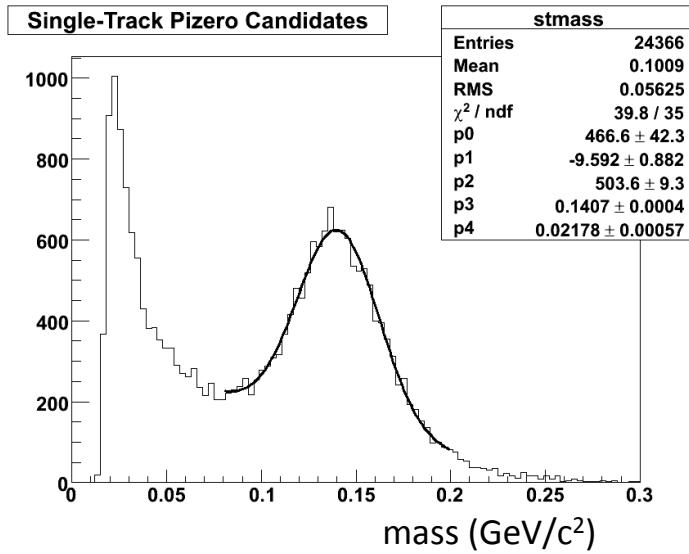


BNL Internal Review on May 11<sup>th</sup>, 2012.

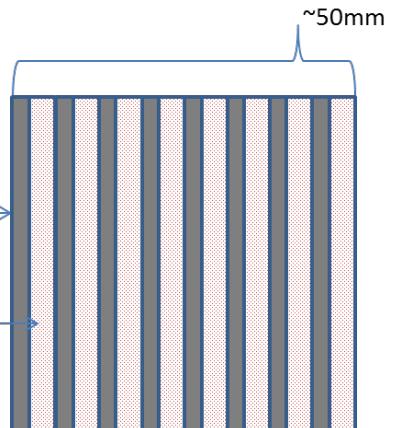
# Minipad Sensors

Detector elements are Si “minipad” detectors, one per tungsten gap, oriented in X and Y (alternating layers).

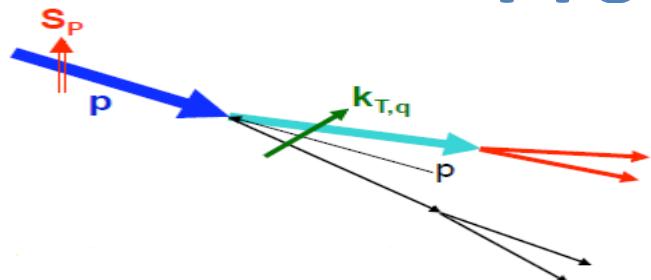
$\pi^0$  mesons reconstructed in p+p jet events ( $E>20\text{GeV}$ )



Cross-Section View:



# Prompt Photon $A_N$

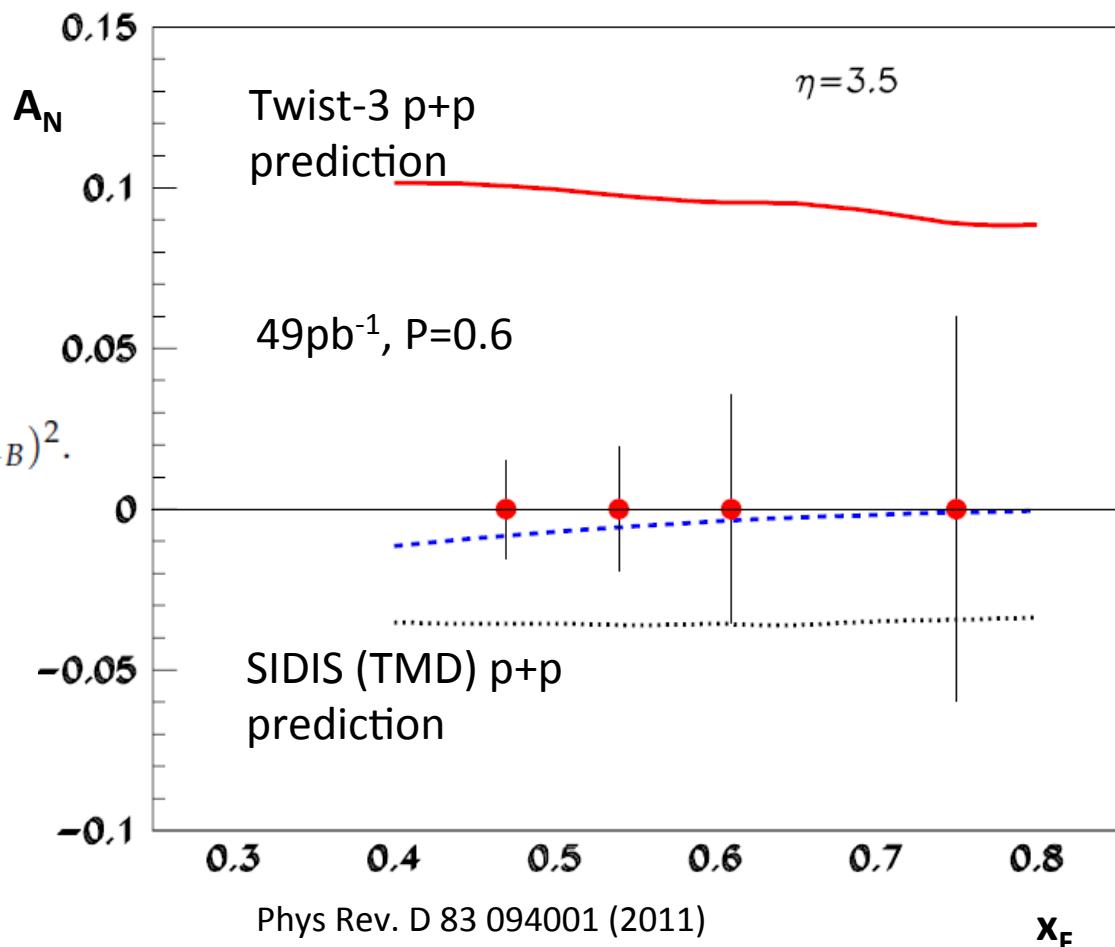


$$A_S = (1 + \frac{1}{r}) A_{meas} - \frac{1}{r} A_B.$$

$\longrightarrow r = S/B = 0.34$

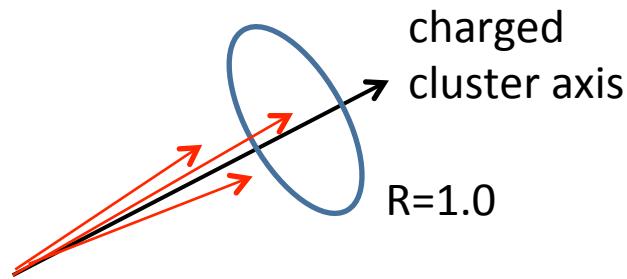
$$(\delta A_S)^2 = (1 + \frac{1}{r})^2 (\delta A_{meas})^2 + (\frac{1}{r})^2 (\delta A_B)^2.$$

- Prompt Photon  $A_N$ 
  - Excellent probe for Sivers
  - Projected error bars assume statistical errors, subtraction of  $\pi^0$  and  $\eta$  photon asymmetry, and 60% polarization

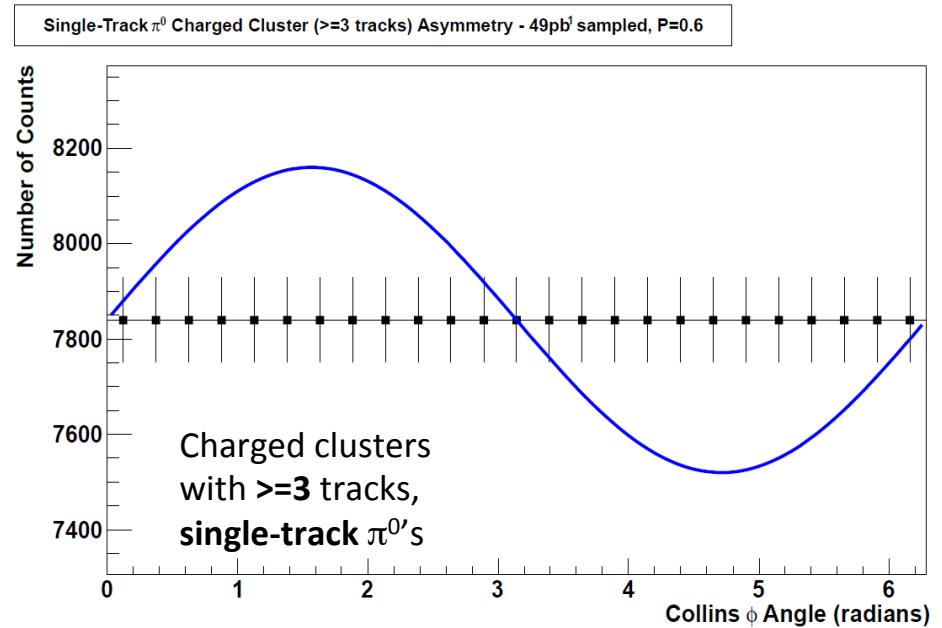
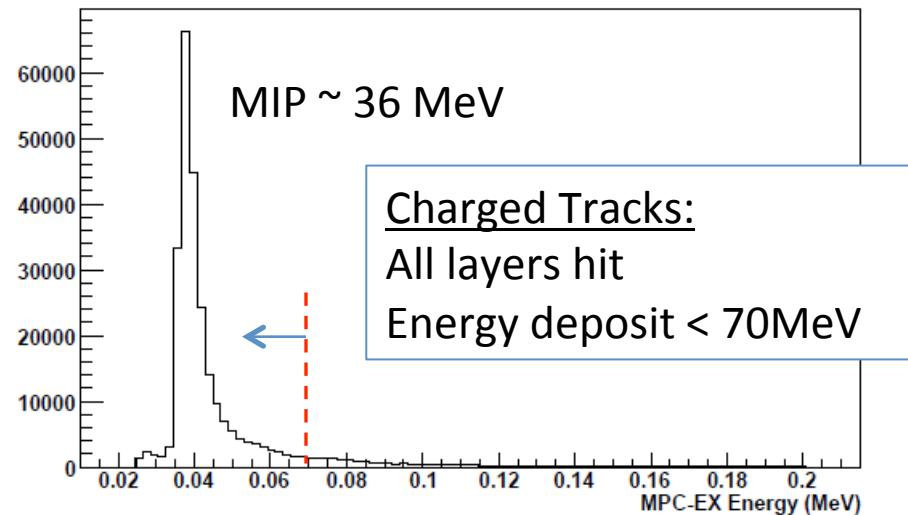
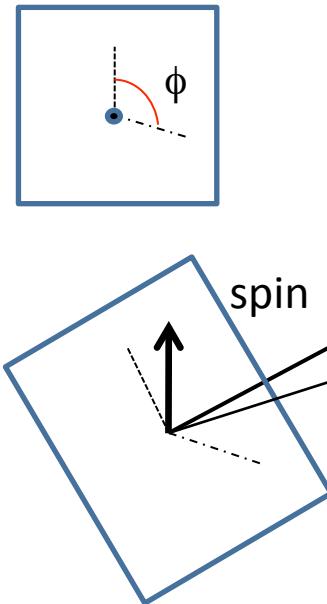


**Prompt photon measurements with MPC-EX will resolve the issue of Sivers sign mismatch.**

# Collins Asymmetry in Jets



- All tracks given equal weight
- Select the cluster with highest number of tracks



# Conclusions

Run12 transverse p+p 200 GeV data:

- $\pi^0$ ,  $\eta$  SSA from MPC data.
- Correlated-hadron SSA.

Run12 had many new developments beyond W-physics:

- FVTX commissioned,
- Heavy Flavor single-muon trigger.

Run13 expect the first polarized Drell-Yan data set  
(longitudinal)

- Double-spin asymmetry  $A_{LL}$
- Single-spin asymmetry  $A_{LU}$

Beyond Run14

- MPC-EX